

Measurement of the Sea Spray Droplet Size Distributions at High Winds

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LONG-TERM GOALS

Improved understanding of fundamental processes of turbulence and sea-spray interactions under very strong wind conditions.

OBJECTIVES

This project will develop cloud droplet probes and phase-Doppler anemometry for measuring size-segregated droplet concentrations at high wind speeds in the ABL. The data will be used for investigating droplet dynamics in the marine atmospheric boundary layer, characterizing the droplet surface flux source function, and determining the effect spray drops have on air-water surface exchange processes. A physically-based parameterization of droplet production in terms of wind/wave variables will be developed.

APPROACH

The fundamental parameter required for representing the effect of sea spray on air-sea exchange processes is the size dependent *source function* for droplets, or number of droplets of a given size produced at the sea surface per unit surface area per unit time as a function of wind speed. Because the source function cannot be measured directly at present, it must be estimated from the height-dependent number-size distribution of droplets, $n(r, z)$ (i.e., the number of droplets of given radius, r , per unit volume of air per increment of radius at height z) and a model for the atmospheric boundary layer that incorporates droplet dynamics. However, progress in determining the source function has been frustrated due to the difficulty of measuring $n(r, z)$. The present droplet source function parameterizations are based on droplet concentrations determined on a beach [Smith *et al.*, 1993], 10 hours of data at a wind speed of 21 m/s from the HEXOS program [de Leeuw, 1990], and inferences

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14. ABSTRACT This project will develop cloud droplet probes and phase-Doppler anemometry for measuring size-segregated droplet concentrations at high wind speeds in the ABL. The data will be used for investigating droplet dynamics in the marine atmospheric boundary layer, characterizing the droplet surface flux source function, and determining the effect spray drops have on air-water surface exchange processes. A physically-based parameterization of droplet production in terms of wind/wave variables will be developed.					
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from various laboratory studies. The data from *Smith et al.* [1993] were recorded for U up to 30 m/s but, besides not being representative of the open ocean, contain no measurements of the larger size ($r > 20 \mu\text{m}$) droplets believed to be important in air-sea exchange processes. In this project two different aircraft-mounted particle-sizing instruments will be used to measure droplet concentrations at high wind speeds (including hurricanes), and this data will be used in droplet dynamics models (Kepert et al., 1999] to estimate droplet source functions at very high wind speeds.

Because droplet measuring instruments often yield conflicting results, we plan to pursue at least two measurement technologies with an emphasis on understanding the measurements and reconciling their disagreements. The first technique is a cloud/precipitation droplet probe (CPDP) based on optical droplet imaging methods. The second droplet measurement method will be based on a phase-Doppler anemometer (PDA). Both cloud droplet probes and PDA's are commercially available and can be deployed from an airplane to measure droplet concentrations. We will conduct these aircraft measurements as part of the intensive field experiments associated with the hurricane science team of the ONR Coupled Boundary Layer/Air-Sea Transfer (CBLAST) DRI. In addition to the aircraft measurements, we will also conduct additional field experiments in the surf zone and laboratory measurements in a wind-wave tunnels.

Dr. Chris W. Fairall from NOAA Environmental Technology Laboratory and Dr. William E. Asher from the University of Washington Applied Physics Laboratory will collaborate on this joint proposal to evaluate both instruments. Dr. Fairall will be direct the measurements made with the CPDP and Dr. Asher will direct the research conducted with the PDA. Drs. Fairall and Asher will collaborate with Dr. Mike Banner (UNSW - University of New South Wales, Australia) on developing a parameterization of droplet production in terms of breaking-wave properties as diagnosed in numerical wave models. The aircraft work will be done in collaboration with Drs. Pete and Robert A. Black, NOAA AOML.

WORK COMPLETED

Funding for this project was received near the end of FY01. In the first year the two main accomplishments were (1) placing an order for a commercially available droplet probe [Model CIP airborne cloud imaging probe from Droplet Measurement Technologies (DMT)], (2) a visit by C. Fairall in July, 2001, to UNSW to meet with Mike Banner and initiate collaboration on linking sea spray production and numerical modeling of oceanic surface wave growth and breaking. In FY02 the CIP was delivered to ETL and personnel were trained in its use. In February C. Fairall met Mike Banner, Simon Change, and Peter Black at the AMS annual meeting in Orlando to discuss plans for the upcoming hurricane season flights on the NOAA aircraft and future wind tunnel work at UNSW. C. Fairall and Peter Black made a trip to McDill AFB to meet with the NOAA OMAO personnel responsible for P-3 operations to discuss installation of the ETL equipment. In May 2002 the system was shipped to McDill AFB in Tampa for integration in the NOAA WP-3D. The cabling was completed and the cabin installation was done. In June 2002 C. Fairall attended the CBLAST meeting in Miami to plan the upcoming field program. The CIP probe was installed in the new wing pod on the P-3 in July 2002. Unfortunately, the wing pod failed its stress test so the probe had to be removed, the pod removed, and OMAO commenced construction of a new wing pod. It is anticipated that the new wing pod will be available before the end of the 2002 hurricane season so data can be obtained this

year. At this writing, we are still awaiting clearance.

RESULTS

Discussions with Mike Banner and associates in 2001 led to the first steps in the development of a new parameterization of sea spray production. The breakdown of the air-sea interface is characterized as a balance of the free energy of droplet formation versus the spectral transfer of TKE which is proportional to the input to wave dissipation by breaking. The introduction of the droplets into the atmosphere is a balance of the slope of their trajectory due to their fall velocity and the distribution of horizontal wind gusts versus the local wave slope. This approach can produce a droplet production size spectral shape similar to existing empirical formulations. An example for HEXOS type conditions is shown in Figure 1. Following the CBLAST meeting in Miami in June 2001, the new model was coded as a MATLAB subroutine and the code was delivered to the numerical modeling group at Penn State University (W. Frank and J. Wyngaard) for use as a droplet source in their LES simulations. A writeup on the model physics was circulated to a list of interested CBLAST investigators.

We are now working with Mike Banner and Bill Asher to develop plans for a January/February 2003 wind tunnel study at UNSW. The ETL CIP and the UW PDA systems will be shipped to Manley, Australia. An experimental planning document is in preparation.

IMPACT/APPLICATIONS

This work will lead to improved treatment of air-sea fluxes for wind speeds exceeding 20 m/s. Primary application will be in numerical forecasting models in conditions with mid-latitude and tropical cyclones.

TRANSITIONS

None

RELATED PROJECTS

“Mid-Oceanic Wintertime Surface Fluxes and Atmospheric Boundary Layer Structure: Relationship to Cyclone Development and Evolution”, NSF. O. Persson, P.I.

SUMMARY

We have taken preliminary steps in formulating a new physical model of sea spray droplet formation and initiated contact with UNSW for laboratory simulations of the processes. A preliminary version of the model has been given to CBLAST numerical model groups. In the fall of 2002 or 2003 we anticipate acquiring long-needed measurements of sea spray concentrations over the oceans in near hurricane force winds. A wind tunnel study is planned for winter of 2003. If successful, we can make progress on a parameterization of spray production and an evaluation of spray thermodynamic effects on hurricanes.

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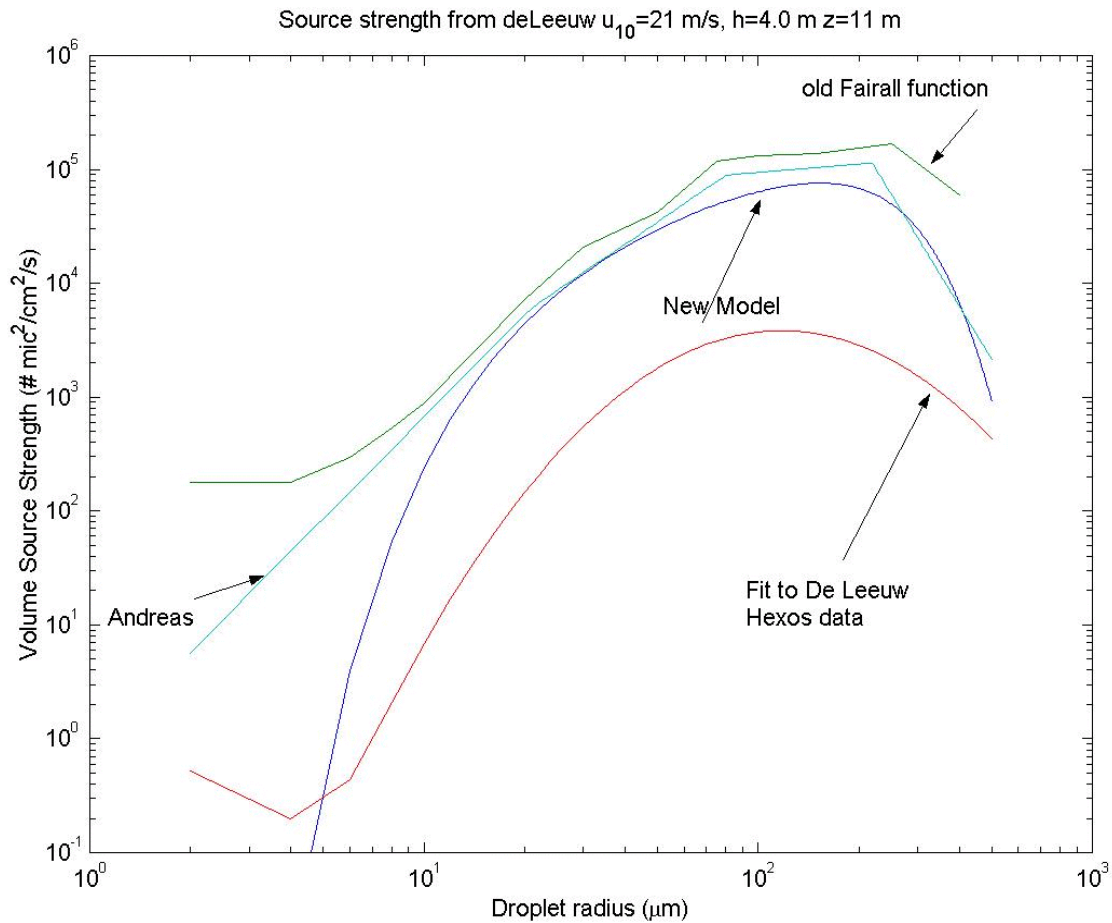


Figure 1. Sea spray droplet volume production size spectrum as a function of droplet radius for a 10-m wind speed of 21 m/s and a significant wave height of 4 m. These are the approximate conditions of the HEXOS experiment droplet concentration data of De Leeuw (1990). Two existing droplet models (one by Fairall and one by Andreas) are shown along with a new scaling result based on De Leeuw's data. The new physical model of Fairall and Banner is shown as the blue curve; one constant has been adjusted to roughly fit the earlier models. In terms of droplet volume (i.e., $4/3\pi r^3$ times the droplet number concentration), the peaks occur for droplets of about 100 micron (0.1 mm) radius. The limiting factor for small droplets is the availability of TKE to form droplets; for large droplets it is the availability of suitable wind gusts to eject the droplets away from the sloping wave surface.

[The droplet production spectrum is the number of droplets of a given radius ejected from the surface per unit area per second. The volume spectrum is the effective water volume assuming the droplets are spheres; multiplied by the density of liquid water, it gives the mass of water in the form of sea spray ejected from the surface.]